Gravity, by George Gamow [Special Archive Article]

Albert Einstein showed that gravitation can be interpreted as a geometrical property of spacetime. His further hope, of relating gravity and electromagnetism, is still unfulfilled

March 4, 2011 | By George Gamow

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Courtesy of Conor L. Myhrvold

In the days when civilized men believed that the world was flat they had no reason to think about gravity. There was up and down. All material things tended naturally to move downward, or to fall, and no one thought to ask why. The notion of absolute up and down directions persisted into the Middle Ages, when it was still invoked to prove that the earth could not be round.

The first ray of light to pierce the mist of scholastic ideas about falling bodies issued from the work of Galileo Galilei. Since free fall was too fast to measure directly, Galileo decided to dilute the motion by studying bodies placed on an inclined plane. He argued—and at the time it was a novel argument—that since a ball resting on a horizontal surface does not move at all, and since a ball falling parallel to a vertical surface moves as fast as it would if the surface were not there, a ball on an inclined surface should roll with an intermediate speed depending on the angle of inclination. Letting balls roll down planes tilted at various angles, he observed their rates of travel and the distances covered in different time intervals, which he measured with a water clock. The experiments showed that at any angle the speed increases in direct proportion to time (counted from the moment of release) and that the distance covered increases in proportion to the square of the time. Galileo also observed that a massive iron ball and a much lighter wooden ball roll down side by side if released simultaneously from the same height on the same inclined plane.

As another way to dilute free fall he employed simple pendulums-weights suspended by thin strings. Here the steepness of the arc along which the weight travels is

adjusted by changing the length of the string. Pendulums of the same length proved to have the same period of oscillation even when the weight was varied, a result in agreement with the outcome of the inclined-plane experiments. From all these observations Galileo was Ied to infer that in free fall all material bodies, light or heavy, also move in exactly the same way. This idea directly contradicted the opinion of the then prevailing Aristotelian school of philosophy, which held that heavier bodies fall faster than light ones. According to the celebrated legend, which may or may not be true, Galileo climbed the leaning tower of Pisa and dropped a light and a heavy ball, which hit tile ground Simultaneously, to the consternation of contemporary philosophers.

Newton's Law of Gravity

These studies laid the foundation for the science of mechanics. The main structure was erected by Isaac Newton, who was born the year Galileo died. With his laws of motion Newton introduced the notions of force and of inertial mass. When a force is applied to material bodies, it changes their speed or direction of motion or both. Their inertial mass opposes these changes. Newton stated that the rate of change of velocity (acceleration) of an object is directly proportional to the force acting on it and inversely proportional to its mass. Doubling the force doubles the acceleration; doubling the mass cuts the acceleration in half; if both force and mass are doubled, the acceleration is unchanged. In the light of this law Galileo's conclusion about free-falling bodies implies a fact that is usually taken for granted, but which is actually very curious; namely, the weight of a body (that is, the gravitational pull of the earth upon it) is strictly proportional to its inertial mass. Otherwise an iron and a wooden ball of the same size would not fall at the same rate. If the two objects have the same acceleration when they are dropped, the inertial mass opposing a change of motion in the iron ball must be greater than that in the wooden ball in exactly the same proportion that the downward force on the iron ball is greater. This proportionality is far from trivial; in fact, it holds true only for gravity and not for other familiar forces such as those of electricity and magnetism. Thus while an electron and a proton would fall with equal acceleration in a gravitational field, when these particles are placed in an electric field the electron is accelerated 1,836 times' faster.

From his analysis of balls (or apples) that fall toward the earth Newton went on to consider gravitation in wider terms. His line of thought is demonstrated by a very interesting discussion in his Principia. Suppose, he said, we shoot a bullet horizontally from the top of a mountain so high that it rises above the atmosphere. The bullet will follow a curved trajectory and hit the surface of the earth some distance away from the base of the mountain. The greater the muzzle velocity, the farther away from the mountain the bullet will land. At a sufficiently high initial velocity the bullet will come to earth at a point directly opposite the mountain; at still higher velocity it will never hit the ground but will continue to revolve around the earth like a little moon. If, Newton argued, it is possible in this way to make an artificial satellite, why not assume that the motion of the natural moon is also a free fall? And if the moon revolves around the earth because of the earth's gravitational attraction, is it not logical to assume that the earth itself is held in orbit around the sun by the force of the sun's gravity? Then is this not also true for all the other planets and their satellites? So originated the profoundly important idea of universal gravitation, which states that all material bodies in the universe attract one another with forces determined by their masses and mutual distances.

To establish the exact relation of force to mass and distance, Newton began by assuming that, since the force between the earth and each body near its surface is proportional to the inertial mass of the body, the force should also be proportional to

the inertial mass of the earth. This immediately explained why the gravitational attraction between bodies of small mass, such as two apples, had never been noticed. It was too weak. Not until half a century after Newton's death was the existence of such a force demonstrated experimentally by another British genius, Henry Cavendish.

Having postulated that the gravitational attraction between two bodies is proportional to the product of their masses, Newton then investigated the dependence on distance. He compared the force necessary to hold the moon in its orbit at the distance of 60 earth radii with the force on an apple at the distance of only one radius from the center of the earth. It is important to realize here that the great difference in mass between the two bodies does not affect the validity of the comparison. As a matter of fact, an apple placed at the m oon's distance and given its orbital velocity will move around the earth exactly as the moon does; by the same token, if one could suspend the moon from a branch, it would fall to the ground exactly as fast as apples do. Newton's mathematical analysis showed that the force of gravity decreases as the square of the distances between the attracting bodies.

He could now write the formula for gravitational force: $F = G\,(M_1 M_2)/d_2$• G is the constant of proportionality, or the gravitational constant. It is a very small number; if the masses are measured in grams and the distance in centimeters, G is approximately .000000066. This means that a pair of one-gram weights separated by one centimeter attract each other with a force a little more than six hundred-millionths of a dyne, or about six hundred-billionths of the weight of a gram.

Combining the law of gravitation with his laws of motion, Newton was able to derive mathematically the rules governing planetary motion that had been discovered by Johannes Kepler. In the memorable era that followed, Newton and his successors explained the motions of celestial bodies down to the most minute details. But the nature of gravitational interaction, and in particular the reason for the mysterious proportionality between gravitational mass and inertial mass, remained completely hidden for more than 200 years.

Einstein's Law of Gravity

Then, in 1914, Albert Einstein lifted the veil. The ideas he put forward grew out of his formulation of the special theory of relativity a decade earlier. That theory is based on the postulate that no observations made inside an enclosed chamber can answer the question of whether the chamber is at rest or moving along a straight line at constant speed. Thus a person in the situation of the author as he writes these lines-in an inside cabin of the *S.S. Queen Elizabeth* sailing on a smooth sea-can perform no experiment, mechanical, optical or any other kind, that will tell him whether the ship is really moving or still in port. But let a storm come up and the situation changes painfully; the deviation from uniform motion is all too apparent.

In order to deal with the problem of nonuniform motion Einstein imagined a laboratory in a spaceship located far from any large gravitating masses. If the vehicle is at rest, or in uniform motion with respect to distant stars, the observers inside, and all their instruments that are not secured to the walls, will float freely. There will be no up and no down. As soon as the rocket motors are started and the ship accelerates, however, instruments and people will be pressed to the wall opposite the direction of motion. This wall will become the floor, the opposite wall will become the ceiling and the people will be able to stand up and move about much as they do on the ground. In fact, if the acceleration is equal to the acceleration of gravity on the surface of the

earth, the passengers may well believe that their ship is still standing on its launching pad.

Suppose one of the passengers simultaneously releases two spheres, one of iron and one of wood, which he has been holding next to each other in his hands. What "actually" happens can be described as follows: While the spheres were held they were undergoing accelerated motion, along with the observer and the whole ship. When they are released, they are no longer driven by the rocket engines. Now they will move side by side, each with a velocity equal to that of the spaceship at the moment of release. The ship itself, however, will continuously gain speed and the "floor" of the ship will quickly overtake the two spheres and hit them simultaneously.

To the observer inside the ship the experiment will look different. He will see the balls drop and hit the "floor" at the same time. Recalling Galileo's demonstration from the leaning tower of Pisa, he will be persuaded that an ordinary gravitational field exists in his space laboratory.

Both descriptions of the observed event are correct; the equivalence of the two points of view is the foundation of Einstein's relativistic theory of gravity. This so-called principle of equivalence between observations carried out in an accelerated chamber and in a "real" gravitational field would be trivial, however, if it applied only to mechanical phenomena. Einstein's deep insight was that the principle is quite general and holds also for optical and other electromagnetic phenomena.

Imagine a beam of light propagating across the space laboratory in a "horizontal" direction. Its path can be traced by means of a series of vertical fluorescent glass plates spaced at equal distances. Again what actually happens is that the beam travels in a straight line at constant speed, while the glass plates move across its path at an ever increasing speed. The beam takes the same time to travel from each plate to the next, but the plates move farther during each successive interval. Hence the pattern of fluorescent spots shows the floor approaching the light beam at an increasing rate. If the observer inside the chamber draws a line through the spots, it will look to him like a parabola bending toward the floor. Since he considers acceleration phenomena as being caused by gravity, he will say that a light ray is bent when propagating through a gravitational field.

Thus, concluded Einstein, if the principle of equivalence holds in all of physics, light rays from distant stars that pass close to the sun on their way to the earth should bend toward the sun. This prediction was brilliantly confirmed in 1919 by a party of British astronomers observing a total solar eclipse in Africa. With the obscuring sunlight extinguished by the moon, stars near the edge of the solar disk were seen to be displaced about 1.75 seconds of arc away from the sun.

Relativistic Merry-Go-Round

Let us next consider another type of accelerated motion-uniform rotation. (A body moving at constant speed on a circular path is accelerated because of its continuous change of direction.) Imagine a merry-go-round with a curtain around it so that people inside cannot tell by looking at the surroundings that it is rotating. If the merry-go-round is turning, the observers will be aware of centrifugal force, which pushes them out toward the rim. A ball placed on the platform will roll away from the center. The centrifugal force acting on any object on the platform will be proportional to the inertial mass of the object, so that here again the effect of accelerated motion can be considered as equivalent to that of a gravitational field. It is a peculiar field, to be sure; it is quite different from the field on the surface of the earth or of any other

spherical body. The force is directed away from the center of the system, not toward it; and instead of decreasing as the square of the distance from the center, it increases proportionately to that distance. Moreover, the field has cylindrical symmetry around a central axis rather than spherical symmetry around a central point. Nevertheless, the equivalence principle holds, and the field can be interpreted as being caused by gravitating mass distributed at large distances all around the symmetry axis.

How will light propagate through this field? Suppose a light source that sends out rays in all directions is located at a point, *A*, on the periphery of the rotating disk, and is observed at a second point, *B*, also on the periphery. According to the basic law of optics, light always propagates along the shortest path. But what is the shortest path between *A* and *B*? To measure the length of various lines connecting the points *A* and *B* the observer uses the old-fashioned but always safe method of counting the number of yardsticks that can be placed end to end along the line.

As we watch the experiment from outside, we recall the special theory of relativity, which tells us that moving yardsticks shrink in the direction of their motion. Therefore we see that if the observer measures along the "true" straight line from *A* to *B*, his sticks will contract and he will need more of them to measure that line than if the platform were not moving. Now an interesting point arises. The closer a yardstick is to the center of the merry-go-round, the less its linear velocity and therefore the smaller its contraction. By bending the line of yardsticks toward the center the observer decreases the number he needs to go from *A* to *B*. Although the "actual" distance is somewhat longer, the increase is more than compensated for by the smaller shrinkage of each yardstick. A light ray following this shortest path, heading inward at the start of its journey and then bending outward, can be considered to be deflected by the apparent gravitational field, which is directed radially outward.

Before leaving the merry-go-round let us consider one more experiment. A pair of identical clocks are placed on the platform, one near the center and the other at the edge. As in the case of the yardsticks, the outer clock is moving faster than the inner one, and again special relativity predicts a difference in their behavior. In addition to causing yardsticks to contract, motion makes clocks run slow. Therefore the outer clock will lose time with respect to the inner one. Now the observer who interprets the acceleration effects in terms of a gravitational field will say that the clock placed in the higher gravitational potential (that is, in the direction in which gravitational force acts) runs slower.

Although we cannot go into details here, Einstein's argument shows that the same effect is expected in a normal gravitational field such as that on the earth. Here the field is directed downward, so that a clock at sea level runs slower than one on top of a mountain. The slowing down applies equally to all other physical, chemical and biological phenomena, and a typist working on the first floor of the Empire State Building will age slower than her twin sister working on the top floor. Stronger fields produce greater retardation. A clock on the surface of the sun would run .0001 per cent slower than a terrestrial clock.

Obviously we cannot put a clock on the sun, but we can watch the rate of atomic vibrations that produce the various lines in the solar spectrum. If these natural clocks are slowed down, the light they emit should be shifted toward the low-frequency, or red, end of the spectrum. This "gravitational red shift" was predicted by Einstein. Such a shift is indeed found in the lines of the solar spectrum, but it is so small as to be almost at the limit of observational precision. Spectra of the much denser white-dwarf

stars, where the red shift is expected to be 40 times larger than on the sun, agree quite well with the theory.

Astronomical evidence is not so satisfying as experiments that can be performed in a terrestrial laboratory. Until a couple of years ago, however, there seemed to be no hope of measuring the minute difference predicted between clocks at different heights in the earth's gravitational field. Then R. L. Mössbauer, working at the University of Munich, found a way to produce nuclear gamma rays of very pure frequency and to measure extremely small changes in their frequency [see "The Mössbauer Effect," by Sergio De Benedetti; SCIENTIFIC AMERICAN, April, 1960]. Seizing on the new opportunity, several workers proceeded to show that two nuclear "clocks" separated by only a few tens of feet in the earth's field run at measurably different rates, and the difference is exactly that predicted by Einstein, within the limits of experimental error. Still another verification, if any more are needed, will almost certainly be obtained when an atomic clock in an artificial satellite is compared with one on the ground.

So we see that in a gravitational field clocks run slow, light rays bend in the direction of the field and a straight line is not the shortest distance between two points. Yet how can one define "straight line" other than as the path of light in a vacuum, or the shortest distance between two points? Einstein's idea was to retain this definition. Instead of saying that light rays and shortest distances are curved, he suggested that space itself (more accurately space-time) is curved. It is difficult to conceive of a curved three-dimensional space, let alone a curved four-dimensional space-time, but some idea of what it means can be gained from an analogy with two-dimensional surfaces. The Euclidean geometry we all learned at school pertains to figures that can be drawn on a plane. If geometrical figures are drawn on curved surfaces, for example a sphere or a surface shaped like a saddle, many of the Euclidean theorems do not hold.

In particular, the sum of the angles of a plane triangle is equal to 180 degrees. In a spherical triangle the sum of the angles is greater than 180 degrees, and in a triangle drawn on a saddle surface it is less. True, the lines forming triangles on spherical and saddle surfaces are not straight from the three-dimensional point of view, but they are the "straightest" (i.e., shortest) lines between the points if one is confined to the surface in question. Mathematicians call such lines geodesic lines, or simply geodesics.

In three-dimensional space a geodesic line is by definition the path along which a light ray would propagate. Consider a triangle formed by three such geodesics. If the sum of the angles is equal to 180 degrees, the space is said to be flat. If the sum is more than 180 degrees, we say that the space is spherelike, or positively curved; if it is less than 180 degrees, we say that it is saddle-like, or negatively curved. Because of the bending of light toward the sun, astronomers located on earth, Mars and Venus would measure more than 180 degrees in the angles of the triangle formed by light rays traveling between the planets. Hence we can say that the space around the sun is positively curved. On the other hand, in the merry-go-round type of gravitational field, the sum of angles of a triangle is less than 180 degrees, and this space is curved in the negative sense.

The foregoing arguments represent the foundation of Einstein's theory of gravity. In the Newtonian view the sun produces in the space around it a field of force that makes the planets move along curved trajectories instead of straight lines. In Einstein's picture space itself becomes curved and the planets move along the straightest (geodesic) lines in that curved space. Here we are speaking of geodesics in the four-

dimensional space-time continuum. It would, of course, be wrong to say that the orbits themselves are geodesic lines in three-dimensional space.

Einstein's interpretation of gravity as the curvature of space-time does not lead to exactly the same results as those of the classical Newtonian theory. We have already mentioned the bending of light. The relativistic theory also gives slightly different answers for the motions of material bodies. For example, it explained the difference between the calculated and observed rates of precession of the major axis of Mercury's orbit, which represented a long-standing mystery of classical celestial mechanics.

Gravity Waves

Newton's law of gravitational interaction between masses is quite similar to the law of electrostatic interaction between charges, and Einstein's theory of the gravitational field has many common elements with James Clerk Maxwell's theory of the electromagnetic field. So it is natural to expect that an oscillating mass should give rise to gravitational waves just as an oscillating electric charge produces electromagnetic waves. In a famous article published in 1918 Einstein indeed obtained solutions of his basic equation of general relativity that represent such gravitational disturbances propagating through space with the velocity of light. If they exist, gravitational waves must carry energy; but their intensity, or the amount of energy they transport, is extremely small. For example, the earth, in its orbital motion around the sun, should emit about .001 watt, which would result in its falling a millionth of a centimeter toward the sun in a billion years!

No one has yet thought of a way to detect waves so weak. In fact, some theorists, among them Sir Arthur Eddington, have suggested that gravitational waves do not represent any physical reality at all but are simply a mathematical fiction that can be eliminated from the equation by a suitable choice of space-time co-ordinates. More thorough analysis indicates, however, that this is not the case and that gravitational waves, weak though they may be, are real.

Are gravitational waves divided into discrete energy packets, or quanta, as electromagnetic waves are? This question, which is as old as the quantum theory, was finally answered two years ago by the British physicist P. A. M. Dirac. He succeeded in quantizing the gravitational-field equation and showed that the energy of gravity quanta, or "gravitons," is equal to Planck's constant, h, times their frequency-the same expression that gives the energy of light quanta or photons. The spin of the graviton, however, is twice the spin of the photon.

Because of their weakness gravitational waves are of no importance in celestial mechanics. But might not gravitons play some role in the physics of elementary particles? These ultimate bits of matter interact in a variety of ways, by means of the emission or absorption of appropriate "field quanta." Thus electromagnetic interactions (for example the attraction of oppositely charged bodies) involve the emission or absorption of photons; presumably gravitational interactions are similarly related to gravitons. In the past few years it has become clear that the interactions of matter fall into distinct classes: (1) strong interactions, which include electromagnetic forces; (2) weak interactions such as the "beta decay" of a radioactive nucleus, in which an electron and a neutrino are emitted; (3) gravitational interactions, which are vastly weaker than the ones called "weak."

The strength of an interaction is related to the rate, or probability, of the emission or absorption of its quantum. For example, a nucleus takes about 10^{-12} second (a millionth of a billionth of a second) to emit a photon. In comparison the beta decay of

a neutron takes 12 minutes—about 10^{14} times longer. It can be calculated that the time necessary for the emission of a graviton by a nucleus is 10^{60} seconds, or 10^{53} years! This is slower than the weak interaction by a factor of 10^{58}.

Now, neutrinos are themselves particles with an extremely low probability of absorption, that is, interaction, with other types of matter [see "The Neutrino," by Philip Morrison; SCIENTIFIC AMERICAN, January, 1956]. They have no charge and no mass. As long ago as 1933 Niels Bohr inquired: "What is the difference between [neutrinos] and the quanta of gravitational waves?" In the so-called weak interactions neutrinos are emitted together with other particles. What about processes involving only neutrinos-say, the emission of a neutrino- antineutrino pair by an excited nucleus? No one has detected such events, but they may occur, perhaps on the same time scale as the gravitational interaction. A pair of neutrinos would furnish a spin of two, the value calculated for the graviton by Dirac. All this is, of course, the sheerest speculation, but a connection between neutrinos and gravity is an exciting theoretical possibility.

Gravity and Electromagnetism

In the laboratory diary of Michael Faraday appears the following entry in 1849: "Gravity. Surely this force must be capable of an experimental relation to electricity, magnetism and other forces, so as to build it up with them in reciprocal action and equivalent effect. Consider for a moment how to set about touching this matter by facts and trial." The numerous experiments he undertook to discover such a relation were fruitless, and he concludes that part of his diary with the words: "Here end my trials for the present. The results are negative. They do not shake my strong feeling of the existence of a relation between gravity and electricity, though they give no proof that such a relation exists." Subsequent experimental efforts have not been any more successful.

A theoretical attack aimed at bringing the electromagnetic field into line with the gravitational field was undertaken by Einstein. Having reduced gravity to the geometrical properties of a space-time continuum, he became convinced that the electromagnetic field must also have some purely geometrical interpretation. However, the "unified field" theory, which grew out of this conviction, had hard going, and Einstein died without producing anything so simple, elegant and convincing as his earlier work. Today fewer and fewer physicists are working at unified-field theory; most are persuaded that the effort to geometrize the electromagnetic field is futile. It seems, at least to the author, that the true relation between gravitational and electromagnetic forces is to be found only through an understanding of the nature of elementary particles-an understanding of why there exist particles with just certain inertial masses and not others-and of the relation between the masses and the electric and magnetic properties of the particles.

As a sample of one of the basic questions in this field, consider again the relative strength of gravitational and electromagnetic interactions. Instead of comparing the times required for emission of quanta, let us compare the actual strength of the electrostatic and gravitational forces between a pair of middleweight particles, say pi mesons. Computation shows that the ratio of electrostatic to gravitational force equals the square of the charge on an electron divided by the square of the mass of the particles times the gravitational constant : $e_2 / M_2 C$. For two pi mesons the value is 10^{40}. Any theory that claims to describe the relation between electromagnetism and gravity must explain this ratio. It should be pointed out that the ratio is a pure number, one that remains unchanged no matter what system of units is used for

measuring the various physical quantities. Such dimensionless constants, which can be derived in a purely mathematical way, often turn up in theoretical formulas, but they are usually small numbers such as 2π, $5/3$ and the like.

How can one derive mathematically a constant as large as 10^{40}? Some 20 years ago Dirac made an interesting proposal. He suggested that the figure 10^{40} is in fact not a constant, but a variable that changes with time and is connected with the age of the universe. According to the evolutionary cosmology, which holds that the universe originated with a "big bang," the universe is now about 5×10^{9} years, or 10^{17} seconds, old. Of course, a year or a second is an arbitrary unit, and we would prefer an elementary time interval that can be derived from the basic properties of matter and light. A reasonable one is the length of time required by light to travel a distance equal to the radius of an elementary particle. Since all the particles have radii of about 3×10^{-13} centimeter, and since the velocity of light is 3×10^{10} centimeters per second, this elementary time unit is 3×10^{-13} divided by 3×10^{10}, or 10^{-23} second. To express the age of the universe in this elementary time unit we divide its age in seconds, 10^{17}, by 10^{-23} and obtain the number 10^{40}! Thus, said Dirac, the large ratio of electric to gravitational forces is characteristic of the present age of the universe. When the universe was half as old as it is now, this ratio was also half of its present value. Since there are good reasons to assume that the elementary electric charge does not change with time, Dirac concluded that the gravitational constant must be decreasing, and that this decrease may be associated with the expansion of the universe and the steady rarefaction of the material that fills it.

If the gravitational constant really has been decreasing, or in other words if the force of gravity has been growing weaker, then our solar system must have been expanding along with the universe. In earlier times the earth would have been nearer the sun and therefore hotter than it is now. When Dirac put forward the idea, the solar system was thought to be about three billion years old. Edward Teller, now at the University of California, pointed out that on such a time scale the earth would have been 50 degrees hotter than the boiling point of water during the Cambrian era, when well-developed marine life existed. Now it seems that the solar system may be five billion or more years old, in which case the Cambrian oceans, though hot, would not have been vaporized. So the objection loses its force, provided that Cambrian plants and animals could live in very hot water.

Antigravity

In one of his stories H. G. Wells describes a British ' inventor, Mr. Cavor, who found a material, called cavorite, that was impenetrable to the force of gravity. Just as sheet copper can shield an object against electric forces and sheet iron can shield against magnetism, a sheet of cavorite placed under a material body would shield it from the gravitational pull of the earth. Mr. Cavor built a large gondola surrounded by cavorite shutters. One night when the moon was high, he got into the ship, closed the shutters facing the ground and opened those facing the moon. Cut off from terrestrial gravity and subjected only to the attraction of the moon, the gondola soared into space and eventually deposited Mr. Cavor on the surface of our satellite.

Why is such an invention impossible? Or is it? There is a profound similarity between Newton's law of universal gravity and the laws that govern the interactions of electric charges and magnetic poles. If one can shield electric and magnetic forces, why not gravity? To answer this question we must consider the mechanism of electric and magnetic shielding. Each atom or molecule in any piece of matter is a system of positive and negative electric charges; in conducting metals there are numbers of

negative electrons that are free to move through the crystal lattice of positively charged ions. Then a metal is placed in an electric field, the free electrons move to one side of the material, giving it a negative charge and leaving the opposite side positive. This polarization produces a new electric field, which is directed opposite to the original field. Thus the two can cancel each other. Similarly, magnetic shielding depends on the fact that the atoms of magnetic materials are tiny magnets, with north and south poles that line up so as to produce a field that opposes an external magnetic field. Here also the shielding effect arises from polarization of atomic particles.

Gravitational polarization, which could make possible shielding against the force of gravity, requires that matter be constituted of two kinds of particles : some with positive gravitational mass, which are attracted by the earth, and some with negative gravitational mass, which are repelled. Positive and negative electric charges and north and south magnetic poles are equally abundant in nature, but particles with negative gravitational mass are as yet unknown, at least within the structure of ordinary atoms and molecules. Therefore ordinary matter cannot be gravitationally polarized and cannot act as a gravity shield.

There is, however, another kind of matter-antimatter-that in many ways is the reverse of ordinary matter, including its electric and magnetic properties. Perhaps antiparticles also have negative mass. At first sight this might seem an easy point to decide. One has only to watch a horizontal beam of antineutrons, say, emerging from an accelerator and see whether the beam bends down or up in the gravitational field of the earth. In practice the experiment cannot be done. The particles produced by accelerators move almost at the speed of light; in a kilometer of horizontal travel gravity would bend them, whether up or down, only about 10^{-12} centimeter, the diameter of an atomic nucleus. Nor can they be slowed down by letting them collide with the nuclei of a "moderator" material, as neutrons are slowed in atomic piles. If antiparticles collide with their ordinary counterparts, both disappear in material annihilation. Thus from the experimental point of view the question as to the sign of the gravitational mass of antiparticles remains painfully open.

From the theoretical point of view it is open too, since we do not have a theory that relates gravitational and electromagnetic interactions. If a future experiment should demonstrate that antiparticles do have a negative gravitational mass, it will deliver a mortal blow to the entire relativistic theory of gravity by disproving the principle of equivalence. An antiapple might fall up in a true gravitational field, but it could hardly do so in Einstein's accelerated spaceship. If it did, an outside observer would see it moving at twice the acceleration of the ship, with no force at all acting on it. The discovery of antigravity would therefore force upon us a choice between Newton's law of inertia and Einstein's equivalence principle. The author earnestly hopes that this will not come to pass.

Comments

Oldest - Newest

Archimedes March 4, 2011, 9:30 AM

Assumptions relating to the properties and physics of gravity are based upon assumptions yet to be proven. They are theories rather than scientific fact. The physical basis of black holes based upon gravity are, also, assumptions. Could it be that gravity and light and matter are CREATED in black holes as was the universe created under similar circumstances? Yes, it is possible. Perhaps, in a hundred years scientists will laugh at the naivete of the scientific community that made the

aforementioned false assumptions with the result that they came to the false scientific conclusions as to the physical properties of gravity and the physics of gravity itself.

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Butchfoote March 4, 2011, 9:48 AM

Ah, and where was that 1st black hole? Where did it come from? Was it CREATED too? All bow down, right?

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ddollisonpa March 4, 2011, 4:29 PM

@archimedes, there are few scientific "facts" as you may or may not understand; there are only theories supported by empiric evidence. Scientific truths may change with the preponderence of evidence provided over time. Currently assumptions made based on Einstein's theory have held true again and again. There is no reason to abandon those principles unless you are bringing forth new data that demonstrates Einstein's folly? You seem to assert that the assumptions discussed here, based on Einstein's theory, are likely to be found false. Care to offer any rationale? Otherwise, your thinking seems rather magical or quite speculative and not really all that credible.

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InquiringConstructivist March 4, 2011, 4:41 PM

<<For example, the earth, in its orbital motion around the sun, should emit about .001 watt, which would result in its falling a millionth of a centimeter toward the sun in a billion years!>> [page 6 of 9 in the web version]

A planet that's lost energy should be further from the sun, no? Tidal energy transfer leads the moon-earth apart.

Can't be right all the time.

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InquiringConstructivist March 4, 2011, 4:46 PM

It would be nice if SciAm bothered to edit this article for scanning errors, including the "I ed" instead of "led" on the first page, and the many problems with exponents of ten. My charity publishes a newsletter with better copy editing, and we get no advertising money and an annual budget of $3000.

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jtdwyer March 4, 2011, 5:42 PM

The discovery of anti-mass and anti-gravitation would be especially interesting, as that would also imply the existence of anti-velocity, anti-acceleration, anti-momentum, etc. All of these effects are directional, their antithetical effects would require the existence of an anti-direction. Enough, already!

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PeterT March 4, 2011, 6:43 PM

Archimedes: You ain't no Archimedes!!

PeterT

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scientific earthling March 4, 2011, 9:02 PM

How do I get a copy of The Mössbauer Effect," by Sergio De Benedetti; SCIENTlFIC AMERICAN, April, 1960

Yes I subscribe to sciam. The archives go back to 1993.

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debu March 4, 2011, 9:35 PM

DURGADAS DATTA published --MISJUDGEMENTS BY NEWTON and BALLOON INSIDE BALLOON THEORY OF MATTER AND ANTIMATTER UNIVERSE in ASTRONOMY.NET in year 2002 . The links are available in durgadas datta face book. GRAVITY and RE CYCLIC UNIVERSE is fully explained and scientists are working on this theory in LHC and NASA.

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ennui March 4, 2011, 11:03 PM

Actually Gravity is related to Electrostatics, not elecrromagnetics.

With an electrostatic potential I can remove an object from clinging to earth. The limestone covers that all the pyramids once had were all removed by lazy people that came to live in Egypt. They built their dwellings with it. No way were the "Egyptians" proud of what the Atlanteans had built around 12,000 years ago. No matter what any person, claiming to be an expert, says.

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